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Review

Safe and sound? A systematic literature review of seizure detection methods for personal use

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ABSTRACT

Purpose: The study aims to review systematically the quality of evidence supporting seizure detection devices. The unpredictable nature of seizures is distressing and disabling for sufferers and carers. If a seizure can be reliably detected then the patient or carer could be alerted. It could help prevent injury and death.
Methods: A literature search was completed. Forty three of 120 studies found using relevant search terms were suitable for systematic review which was done applying pre-agreed criteria using PRISMA guidelines. The papers identified and reviewed were those that could have potential for everyday use of patients in a domestic setting. Studies involving long term use of scalp electrodes to record EEG were excluded on the grounds of unacceptable restriction of daily activities.
Results: Most of the devices focused on changes in movement and/or physiological signs and were dependent on an algorithm to determine cut off points. No device was able to detect all seizures and there was an issue with both false positives and missed seizures. Many of the studies involved relatively small numbers of cases or report on only a few seizures. Reports of seizure alert dogs are also considered.
Conclusion: Seizure detection devices are at a relatively early stage of development and as yet there are no large scale studies or studies that compare the effectiveness of one device against others. The issue of false positive detection rates is important as they are disruptive for both the patient and the carer. Nevertheless, the development of seizure detection devices offers great potential in the management of epilepsy

1. Introduction

One of the most disabling aspects of epilepsy is the unpredictability of epileptic seizures. During a seizure a person is generally unaware and unable to call for help. Many people with epilepsy or their carers keep seizure diaries, but there is a difference between recording and detecting seizures and diaries have been shown to be rather unreliable [1]. However, the use of a detecting devise linked to an electronic diary could be of practical benefit for the seizure management. The aim of this study is to systemically review the quality of evidence supporting seizure detection devices.

2. Theory

Seizure detection studies have focused on detecting physiological changes that occur before and during a seizure. Such as increased cerebral oxygen levels, alteration of movements, heart rate changes, electrical activity in muscles and changes in galvanic skin resistance. In addition there are also studies of dogs that appear to detect seizures. This review paper describes studies that have practical implications for clinical practice.

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3. Material and methods

A literature search was carried out using the search terms: epilepsy, epileptic, seizure, alarm, monitor, device, sensor, safety, protection, mobile/smart phone, pillow, mat, mattress, physiologic, accelerometer, home, community, moisture, technology. The following databases – Medline, Cinal and Embase were used for this review. In addition 9 organisations were contacted for details of any relevant studies. Only one organisation provided a further study that was not included in the original literature search. Altogether, 120 studies were examined. 68 of the papers were excluded from the review because they involved the use of scalp electrodes to continuously record EEG data. Not only was this very intrusive and impractical for everyday life but the majority of patients would refuse to wear on a long term basis [2]. Similarly 4 studies were excluded because they involved implanted devices and were not relevant for most people with epilepsy.

The remaining 48 studies were then assessed using the guidance of the PRISMA [3] on the following 5 criteria for inclusion in this review:

1. use of control cases
2. confirmed diagnosis
3. 10 or more cases
4. identification of false positives
5. quality of life mentioned

The criteria was decided and confirmed by an expert focus group. None of the studies met all 5 of the inclusion criteria, but 19 met at least 3 and form the basis of this review. A further 16 studies were included because they added interesting information even though they failed to meet the inclusion standard. They are marked in the text with an asterisk.

4. Results

4.1. Movement sensors

A pressure sensor mat is placed under the sheet or mattress to detect abnormal movement or absence of movement. They can usually be adjusted to allow for the patient's weight and for normal sleep movements. Nevertheless they were very variable in their success in detecting seizures. The most successful device ($n = 79$) detected 89% of tonic clonic seizures [4]. But another study detected only 30% of nocturnal tonic clonic seizures ($n = 45$) [5]. In a study comparing two seizure movement alarms corroborated by vEEG, one alarm didn't detect any nocturnal seizures whilst the other detected 66% ($n = 15$) [6].

The specificity of movement monitors is questionable. One study ($n = 64$) recorded 269 false positive results [7]. While another study noted numerous false alarms and 28 patients had to be excluded from the study due to faulty sensors, false positives and difficulties differentiating seizures from movements associated with getting out of bed [4].

In spite of these problems, this type of sensor is currently the first choice for many people, perhaps because of its simplicity [8]. A study carried out by the Maxwell Muir Foundation found that 90% of parents were satisfied with bed sensors for their children and believed that most seizures were detected in spite of false alarms (Panwar, unpublished) [40].

4.2. Accelerometers

An accelerometer is a device that measures both motion and changes in velocity in either 2 or 3 dimensions. For example, smart phones have a 3-way axis which detects when they are tilted, rotated, or moved. A study [9] pointed out that vEEG was too uncomfortable for long term use and that wearing small accelerometers on the limbs was user friendly and able to provide long term monitoring of tonic clonic seizures. A sensitivity of 95% was observed in a study ($n = 7$) using four accelerometers, but with noticeable inter-patient difference [10]. This was supported by the finding of another study ($n = 73$) which showed a sensitivity of 91% using a single wrist worn unit [11]

The specificity and sensitivity of an accelerometer is dependent on the associated algorithm to analyse the rate, amplitude, intensity, duration and rhythm of the motor component of the seizure and it has been suggested that a minimum of two accelerometers are needed to reliably detect nocturnal convulsive seizures [12]. However it was reported on a commercially available smart watch that could be worn on any limb and had the advantage of communicating with a smartphone via Bluetooth and the ability to set the sensitivity [13]. 15 patients were monitored with vEEG and all generalised tonic clonic seizures (GTCS) were identified. A similar set up with a single wrist attached device and vEEG monitoring detected 87% of GCTS but with multiple false positives [14]

Most studies report on small numbers of cases with variable specificity (correctly identifying genuine seizures). Ceulemans et al. [15] noted a specificity of 84% ($n = 3$) with clearly marked motor manifestations in their nocturnal seizures, but Van De Vel et al. [16] noted a specificity of only 58% for nocturnal hyper motor seizures in seven patients. In a larger study of 49 patients Van De Vel et al. [17] found that no parameter setting was 100% sensitive or specific for all patients. They observed a specificity between 35% and 100% in detecting seizures.

False positive rates also vary. Beniczky et al. [11] observed a very low false positive rate of once every 5 days ($n = 73$) while Sabesan et al. [18] found a higher mean false positive of 2.1 per night in a multi-modal device incorporating both an accelerometer and ECG. The speed of seizure detection is also an important factor and Kramer et al. [19] found that 91% of seizures were detected within a median period of 17 s, and all events were identified within 30 s.

4.3. Devices that measure physiological change

Seizure onset can be detected by changes in the autonomic nervous system [20]. A pilot study by Poh et al. [21] observed that epileptic seizures induce a decrease in skin resistance due to increased sweating. A further study based on galvanic skin resistance and accelerometers in seven patients found that the device detected 94% of the generalised tonic clonic seizures (GTCS) with a false positive rate of 0.74 per 24 h. [22]

Seizure detection using heart rate has been observed to correlate well with electrocorticoencephalography (ECoG) However, this varied from person to person and its clinical relevance is unproven [23]

Physiological signals of movement and heart rate were assessed for home seizure detection in 92 patients, but a high sensitivity was found to be necessary for algorithms to be implementable [24]. Kroner et al. [25] measured heart rate, respiration and electromyography ($N = 7$) and concluded that cardiac parameters alone were able to identify 100% of GTCS and 94% of myoclonic seizures. Other physiological approaches for detecting seizures have been investigated such as the use of an apnoea device worn over the trachea which identified 88% of sleep apnoea events in 10 subjects and a specificity of 99% (Rodruigez-Villegas et al., 2014) [39].